PREDICTIVE EQUATIONS FOR SUSPENDED SOLIDS AND DISSOLVED OXYGEN IN THE HIGHWOOD RIVER

Alberta
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PREDICTIVE EQUATIONS FOR SUSPENDED SOLIDS AND DISSOLVED OXYGEN IN THE HIGHWOOD RIVER

Prepared by:

Al Sosiak, M.Sc.
Limnologist

Air and Water Branch
Science and Standards Division
Environmental Assurance

October 2001

Pub No. T/617
ISBN No. 0-7785-1890-6 (Printed Edition)
ISBN No. 0-7785-1903-1 (On-Line Edition)
Web Site: http://www.gov.ab.ca/env/

Any comments, questions, or suggestions regarding the content of this document may be directed to:

Science and Standards Division
Alberta Environment
4th Floor, Oxbridge Place
9820 – 106th Street
Edmonton, Alberta T5K 2J6
Phone: (780) 427-5883
Fax: (780) 422-4192

Additional copies of this document may be obtained by contacting:

Information Centre
Alberta Environment
Main Floor, Great West Life Building
9920 – 108th Street
Edmonton, Alberta T5K 2M4
Phone: (780) 944-0313
Fax: (780) 427-4407
Email: env.infocent@gov.ab.ca

ACKNOWLEDGMENTS

I thank all technical and professional staff of Alberta Environment who assisted in the monitoring of the Highwood River. Bridgette Halbig assisted in data compilation and report preparation. Dave Trew provided review comments on the draft report.

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1.0 INTRODUCTION

Under the current operating guidelines, diversion of water from the Highwood River ceases when water temperature is greater than 24°C or dissolved oxygen falls below 5 mg/L. These operating guidelines have been included in modelling designed to determine the water supply that is available for irrigation and other consumptive uses. An earlier predictive equation for dissolved oxygen in the Highwood River (p. 26, APWSS 1995) included a term for aquatic plant biomass, because high levels of plant biomass caused low levels of dissolved oxygen at night before 1990 (Appendix I). However, macrophyte biomass has decreased and dissolved oxygen in the Highwood River at Aldersyde has increased since September 1989, when the Town of High River stopped discharging wastewater to the Highwood River.

To assist modelling of water supply under current conditions in the Highwood River, the Water Quality Section of Alberta Environment (AENV) was asked to develop equations that can be used to predict minimum dissolved oxygen in the Highwood River downstream from High River, based on daily maximum water temperature. The Water Quality Section was later asked by Alberta Transportation to also provide an equation that can be used to predict total suspended solids or turbidity based on flow. This request was prompted by a need to evaluate the potential water quality impacts of various flow recommendations for the Highwood River. This report presents equations that can be used to predict total suspended solids and dissolved oxygen as functions of flow and maximum water temperature, respectively.

2.0 METHODS

Maximum daily water temperature in the Highwood River at the Aldersyde datasonde site, and minimum dissolved oxygen concentration later the same day or early the following day were compiled for 1990 to 1997 and included in the regression analysis. Datasondes were installed for at least the period from early July to the first week of September, but units were operated for longer periods some years (Appendix I). These meters recorded dissolved oxygen, water temperature, pH and conductivity, at least hourly. Approved Water Survey of Canada daily mean flows for the Highwood River below the Little Bow Canal (site 05BL004) were used for each year. Environment Canada supplied maximum daily air temperatures for the Calgary Airport weather station. Water temperatures, dissolved oxygen concentrations, flows and air temperatures for 1998 to 2000 were also reviewed to determine whether guidelines were met at certain flows.

To improve the accuracy of the regression analysis, the water temperature and dissolved oxygen data were divided into smaller data sets. Higher water temperatures were recorded when flows in the river were in the range 4.26 - 8 m^3/s than when flows were > 8 m^3/s (Figures 1 to 3). Under the operating guidelines for the Highwood River, < 150 ft^3/s (4.26 m^3/s) is considered low flow conditions. Modelling by Cross (1989) predicted that high water temperatures would be unlikely to occur at flows > 8 m^3/s. Therefore, the data were divided into three smaller datasets using the following criteria: (a) < 4.26 m^3/s; (b) 4.26-8 m^3/s; (c) > 8 m^3/s. Note that these criteria use the same number of significant figures as were used in the source documents.

The highest water temperatures and lowest dissolved oxygen levels generally occurred during mid-summer, between July 15 and August 15 (Appendix I). Accordingly, data from midsummer in each dataset were analyzed separately, with midsummer defined as July 15 to August 15, except where flows were < 4.26 m^3/s. Due to the small sample size at these low flows from August 1-15 ($N = 2$), data for the entire month of August were included in the summer period for flows < 4.26 m^3/s.

Total suspended solids and turbidity have been sampled at various locations along the Highwood River. However, the only location with sufficient recent data for regression analysis was at the Little Bow Canal immediately downstream from the diversion works (site AB05AC0066), which was grab-sampled during March 22, 1999 to August 31, 2000 (N_{TSS}= 57). This sampling site is approximately 20 m from the diversion, and was therefore assumed to represent Highwood River water quality. The only variable with sufficient data was total suspended solids, measured as nonfilterable residue. Bank erosion and resuspension of shoreline sediments were assumed to be important sources of sediment in this reach of the Highwood River. Accordingly, three samples collected December 9, 1999 to February 17, 2000, when the bank and shoreline were likely frozen, were excluded from the regression analysis. Mean daily flows for the Highwood River at site 05BL004 were used in the regression analysis.

Minimum dissolved oxygen (the dependent variable) was regressed against maximum water temperature (independent variable). Similarly, total suspended solids (as nonfilterable residue) was regressed against flow. The 13 linear and non-linear regression models available in the water quality statistics package WQHYDRO (Aroner 1995) were evaluated. Only those models that were statistically significant were refined using a robust regression procedure, which minimizes the effects of data with large residuals. The models with lower standard errors were then compared to measured data, and the model which best matched the observed data in each case was selected. The water temperature corresponding to the current operating guideline (5 mg/L) and the Canadian Environmental Quality (CEQ) guideline for dissolved oxygen (other life stages, cold water: 6.5 mg/L, CCME 1999) was then determined using an iterative procedure in Excel 7.0.

3.0 RESULTS AND DISCUSSION

Results of the analysis are presented in Tables 1 and 2, and Figures 1 to 12, and are discussed in the following sections. Dissolved oxygen, flow, and air and water temperature data used to develop and evaluate the dissolved oxygen equations are compiled in Appendix I.

3.1 Effects of Flow on Water Temperature

The range and distribution of maximum water temperature recorded at lower flows differed from that recorded at high flows. Higher water temperatures were recorded when flows were in the range of 4.26-8 m^3/s, than when river flows were greater than 8 m^3/s (Figures 1 and 2). However, the range and distribution of peak water temperature at flows under 4.26 m^3/s (Figure 3) was similar to that found at flows greater than 8 m^3/s (Figure 1). Flows under

4.26 m^3/s only occurred late in the monitoring season during 1990 to 1997, between August 7-October 5, when air temperatures were cooler and day length was decreasing.

Using the WQRRS water quality model, Cross (1989) determined that a flow of 8 m^3/s would prevent the water temperature in the Highwood River from increasing above 24°C during hot weather. Most of the datasonde results from 1989-2000 support this conclusion. Although air temperatures reached 29°C in 1990, 1991, 1994 (Appendix I) and 1999, water temperature were not greater than 24°C during these years if flows were greater than 8 m^3/s. However, water temperatures were greater than 24°C when air temperatures were 29° C or higher, and flow was under 8 m^3/s in 1989, 1994, and 2000. Water temperature briefly peaked at 25.3° C on July 27, 1998 at a flow of 12.0 m^3/s after four days of maximum air temperatures $\geq$ 28° C. This finding suggests that the 8 m^3/s recommendation by Cross (1989) may not always protect water temperature during hot weather.

3.2 Predictive Equations for Dissolved Oxygen

Regression equations that best predicted dissolved oxygen in the lower Highwood River are presented in Table 1 and are plotted in Figures 4 to 11. Equations developed for midsummer had lower standard errors and fit the observed data better than equations developed for the spring and fall period. The midsummer equations predicted a sigmoidal relationship between dissolved oxygen and water temperature, with rapidly declining dissolved oxygen at high temperatures. This rapid decline in dissolved oxygen at high temperatures may partially reflect a greater impact of oxygen demand from aquatic plants, especially at low flows.

3.3 Water Temperature at Dissolved Oxygen Guidelines

The regression equations in Table 1 were used to predict the water temperature at which dissolved oxygen will reach the current operating (5 mg/L) and the CEQ (6.5 mg/L) dissolved oxygen guidelines. Dissolved oxygen should only fall below the CEQ guideline in midsummer when flows are below 8 m^3/s (Table 2), and at water temperatures above the current 24°C guideline at which irrigation diversions are curtailed. Water temperature will therefore remain the most restrictive variable.

The equations predict that dissolved oxygen will fall below the 6.5 mg/L guideline in midsummer, when water temperatures is greater than 25.8°C, at flows below 8 m^3/s (Table 2). Dissolved oxygen only fell below this guideline when flows dropped below 8 m^3/s in 1994, at a maximum daily water temperature of 25.97°C, 1999 (23.30°C), and 2000 (23.63°C). Note that water temperatures were recorded to two decimal places each year. The equations also predict that dissolved oxygen will only fall below the current 5-mg/L guideline at a water temperature of about 29.0°C, at flows below 8 m^3/s. Temperatures of 29.0°C greatly exceed the maximum water temperature recorded during 1989-2000 (26.0°C) and should only occur if air temperatures are much higher than in 1989-2000. Similarly, the equations predict that the dissolved oxygen will only fall below the two guidelines in spring and fall at water temperatures well above any that have been recorded in the Highwood River at that time of year (Table 2).

Table 1 **Regression equations for total suspended solids (TSS) and minimum dissolved oxygen (DO_{min}) as functions of flow (Q) and maximum water temperature (T_{max}), respectively, in the Highwood River at Aldersyde**

Flow Range (m^3/s)	Time Period	Predictive Equation	r2	SE
DISSOLVED OXYGEN (MIDSUMMER)				
> 8	July 15-Aug.15	$DO_{min} = EXP[20.583 + (-19.916*(LN(T_{max}))) + (7.2224*(LN(T_{max})^2))+(-0.879436*LN(T_{max})^3))]$	0.703	0.179
4.26-8	July 15-Aug.15	$DO_{min} = EXP[196.65+(-193.92*(LN(T_{max}))) + (64.504*(LN(T_{max})^2)) + (-7.16214*(LN(T_{max})^3))]$	0.741	0.242
< 4.26	Aug. 1-30	$DO_{min} = EXP[37.09+(-38.359*(LN(T_{max}))) + (14.057*(LN(T_{max})^2)) + (-1.72079*(LN(T_{max})^3))]$	0.843	0.115
DISSOLVED OXYGEN (REST OF THE SEASON)				
> 8	Before July 15, after Aug.15	$DO_{min} = EXP[2.5941+(-0.013616*(LN(T_{max})))+(-0.05275*(LN(T_{max})^2))]$	0.805	0.283
4.26-8	Before July 15, after Aug.15	$DO_{min} = 12.082*(EXP(-0.02045* T_{max}))$	0.867	0.261
< 4.26	After Aug.30	$DO_{min} = 18.093+(-3.3639*(LN(T_{max})))$	0.758	0.383
TOTAL SUSPENDED SOLIDS (OPEN WATER SEASON)				
≤ 40.3	March 22-Nov. 18	$TSS = 0.997286*Q^{0.837983}$	0.376	15.539

Table 2 **Water temperatures (°C) at which dissolved oxygen in the Highwood River at Aldersyde is predicted to reach dissolved oxygen guidelines**

Flow Range (m^3/s)	Time Period	6.5 mg/L	5 mg/L
MIDSUMMER			
> 8	July 15-Aug.15	28.08	33.82
4.26-8	July 15-Aug.15	25.77	28.90
< 4.26	Aug. 1-30	25.03	29.02
REST OF THE SEASON			
> 8	before July 15, after Aug.15	> 35.00	> 35.00
4.26-8	before July 15, after Aug.15	30.31	> 35.00
< 4.26	after Aug.30	31.38	> 35.00

3.4 Effects of Flow on Total Suspended Solids

A statistically significant relationship between flow and total suspended solids (as nonfilterable residue) was found in this analysis (Table 1). Total suspended solids increased more with increasing flow below about 20 m^3/s (Figure 12). At one of the flow recommendations that will be evaluated, 1200 ft^3/s (33.98 m^3/s)(J. Englert. 2001. Personal communication), total suspended solids of 19.1 mg/L was predicted by the equation in Table 1.

This equation should be considered valid only for the ranges of flow (2.06-40.3 m^3/s) and total suspended solids (0.4-261 mg/L) that were included in the analysis. A different relationship may exist for these variables outside these ranges.

4.0 CONCLUSIONS

The main conclusions of this analysis are as follows:

1. The equations produced in this analysis predict that dissolved oxygen will fall below the CEQ guideline of 6.5 mg/L in midsummer at water temperatures above 25.8°C and flows under 8 m^3/s. They further predict that dissolved oxygen will not fall below the current operating guideline of 5.0 mg/L in midsummer under typical water temperatures, and dissolved oxygen will remain above both guidelines at other times of the year.
2. These equations were developed for the range of air and water temperatures, and aquatic plant biomass that occurred during specific time periods from 1990 to 1997, in the Highwood River between High River and Aldersyde. These equations may not accurately predict dissolved oxygen in other reaches or under higher water temperatures or aquatic plant biomass.
3. These equations would not be accurate if aquatic plant biomass increases significantly. If this occurs, the predictive equation in APWSS (1995) should be used.
4. Total suspended solids increased significantly with increasing flow in the Highwood River. The equation that has been developed should only be considered valid for the ranges of flow and total suspended solids that have been included in the analysis.

5.0 LITERATURE CITED

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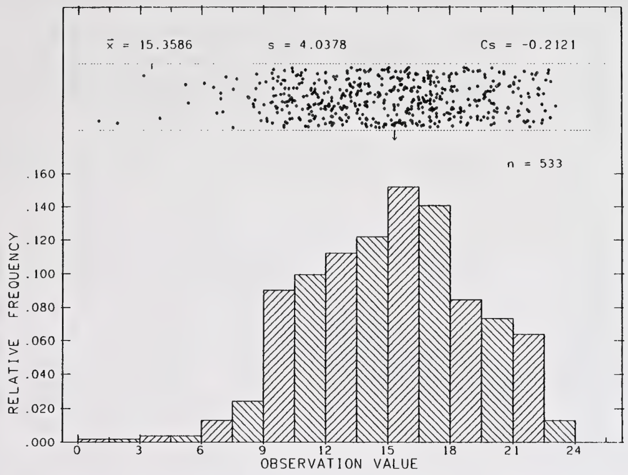


Figure 1 **Maximum daily water temperature in the Highwood River at Aldersyde at flows > 8 m^3/s, 1990-97**

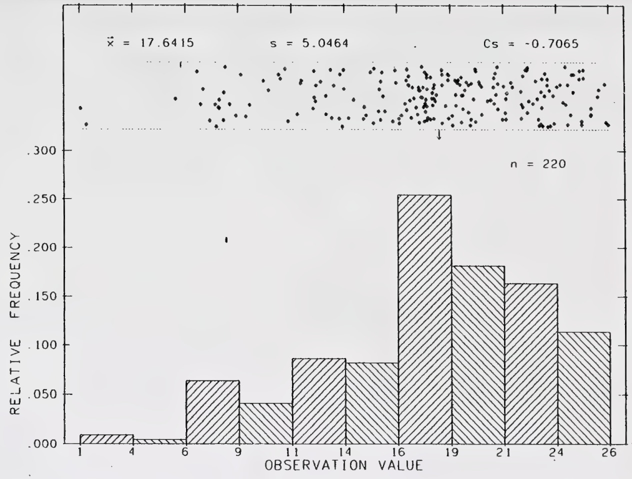


Figure 2 **Maximum daily water temperature in the Highwood River at Aldersyde at flows of 4.26-8 m^3/s, 1990-97**

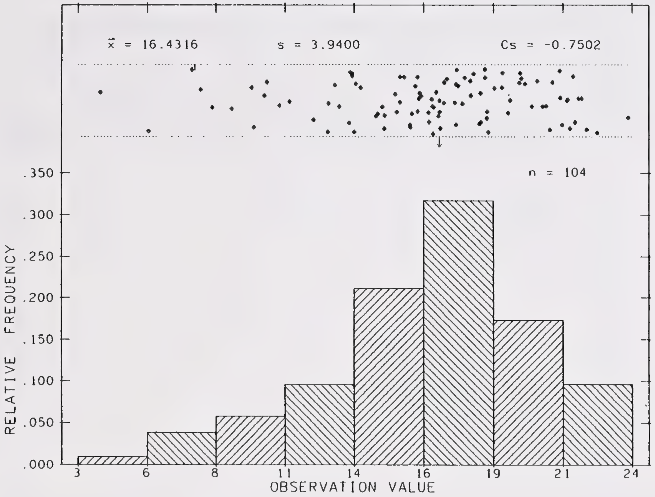


Figure 3 **Maximum daily water temperature in the Highwood River at Aldersyde at flows of < 4.26 m^3/s, late summer, 1990-97**

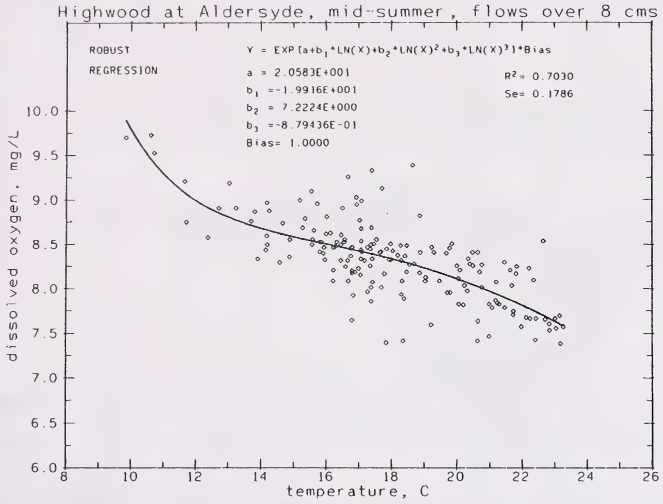


Figure 4 Regression between daily minimum dissolved oxygen and maximum water temperature in the lower Highwood River in midsummer, 1990-97

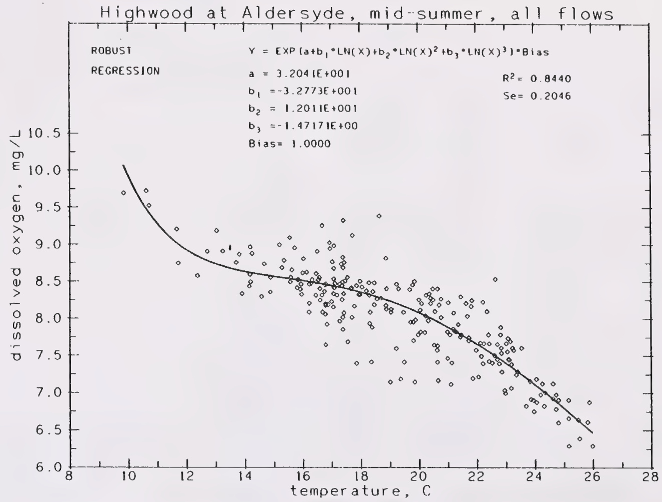


Figure 5 Regression between daily minimum dissolved oxygen and maximum water temperature in the lower Highwood River at flows > 8 m^3/s in midsummer, 1990-97

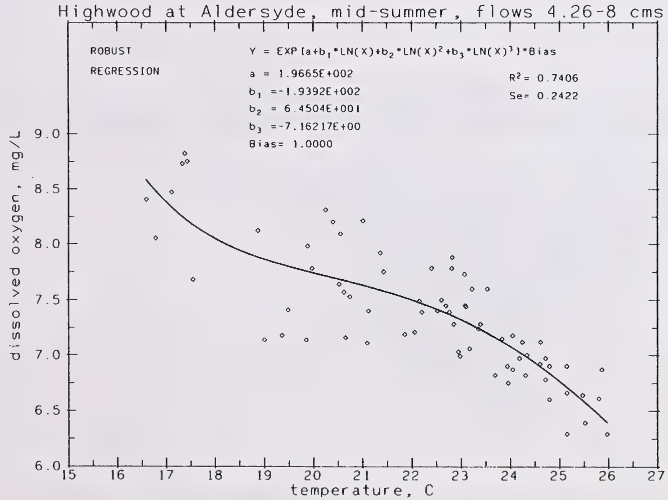


Figure 6 Regression between daily minimum dissolved oxygen and maximum water temperature in the lower Highwood River at flows 4.26-8 m^3/s in midsummer, 1990-97

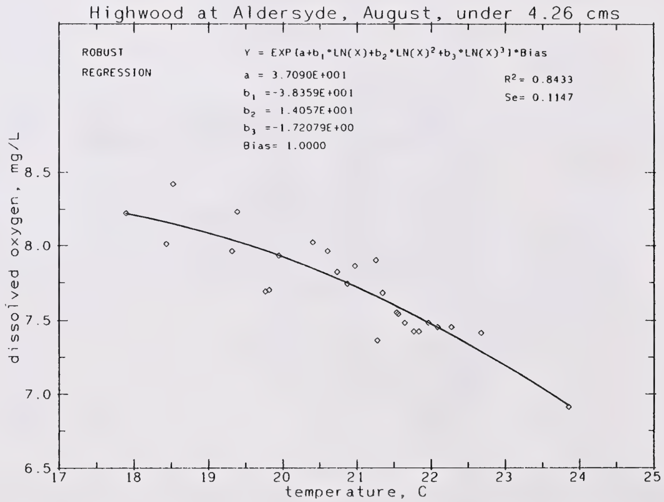


Figure 7 Regression between daily minimum dissolved oxygen and maximum water temperature in the lower Highwood River at flows <4.26 m^3/s in midsummer, 1990-97

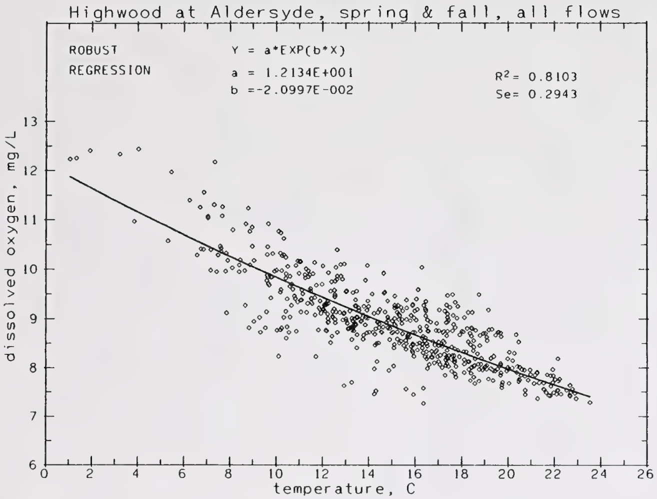


Figure 8 Regression between daily minimum dissolved oxygen and maximum water temperature in the lower Highwood River in spring and fall, 1990-97

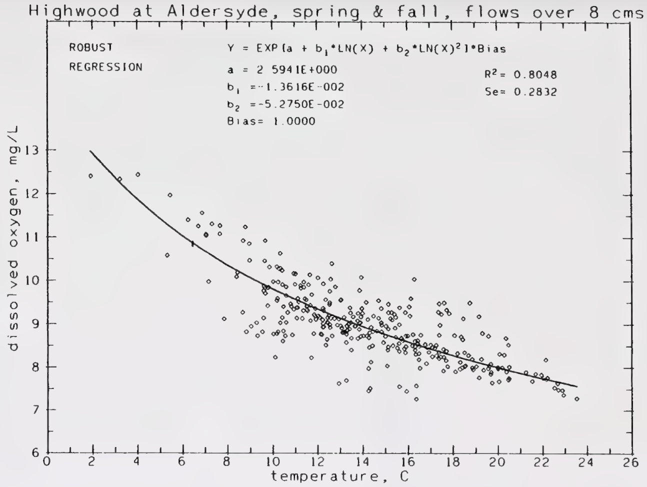


Figure 9 Regression between daily minimum dissolved oxygen and maximum water temperature in the lower Highwood River at flows >8 m^3/s in spring and fall, 1990-97

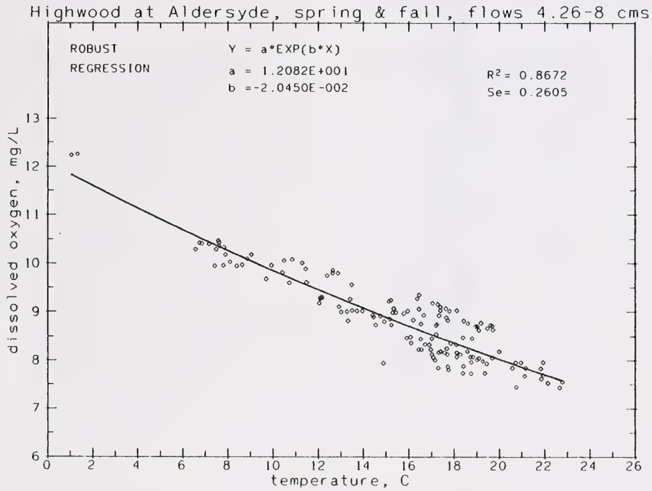


Figure 10 Regression between daily minimum dissolved oxygen and maximum water temperature in the lower Highwood River at flows 4.26-8 m^3/s in spring and fall, 1990-97

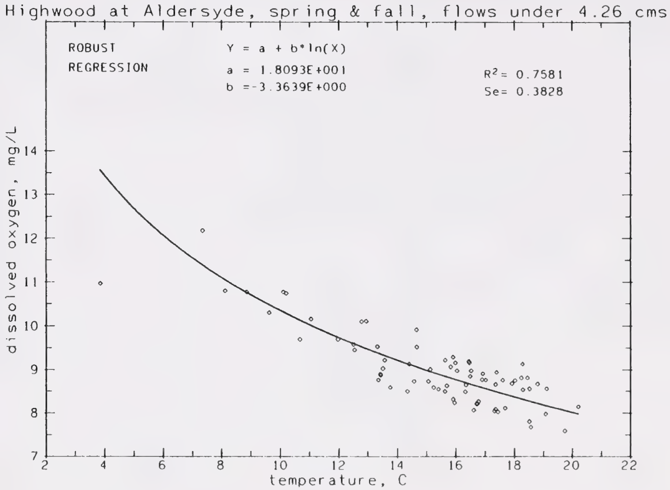


Figure 11 Regression between daily minimum dissolved oxygen and maximum water temperature in the lower Highwood River at flows <4.26 m^3/s in spring and fall, 1990-97

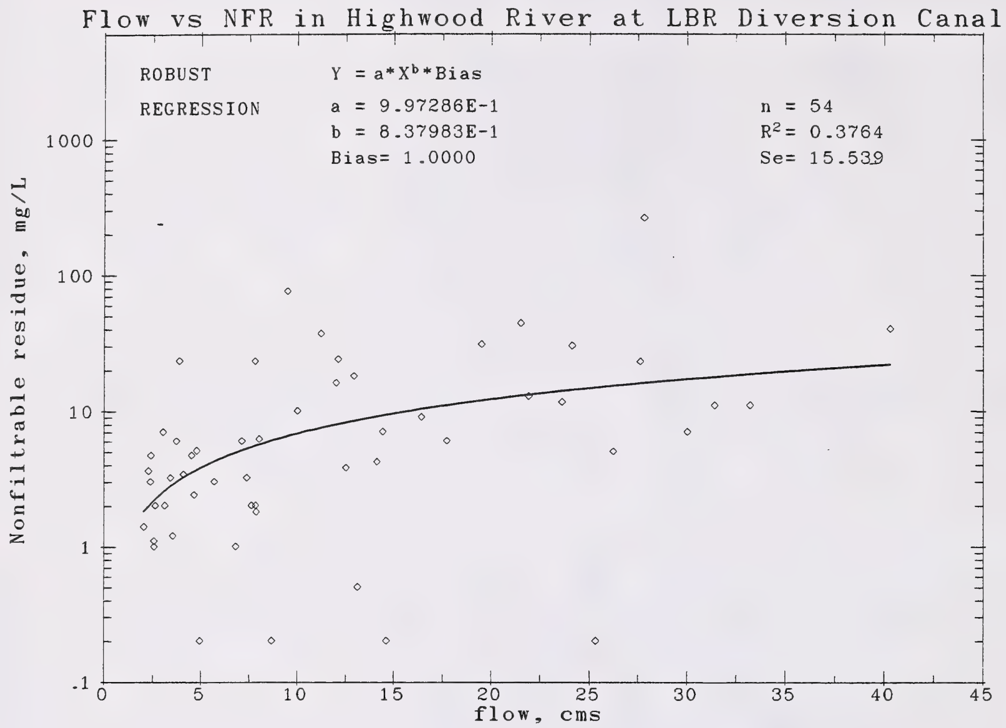
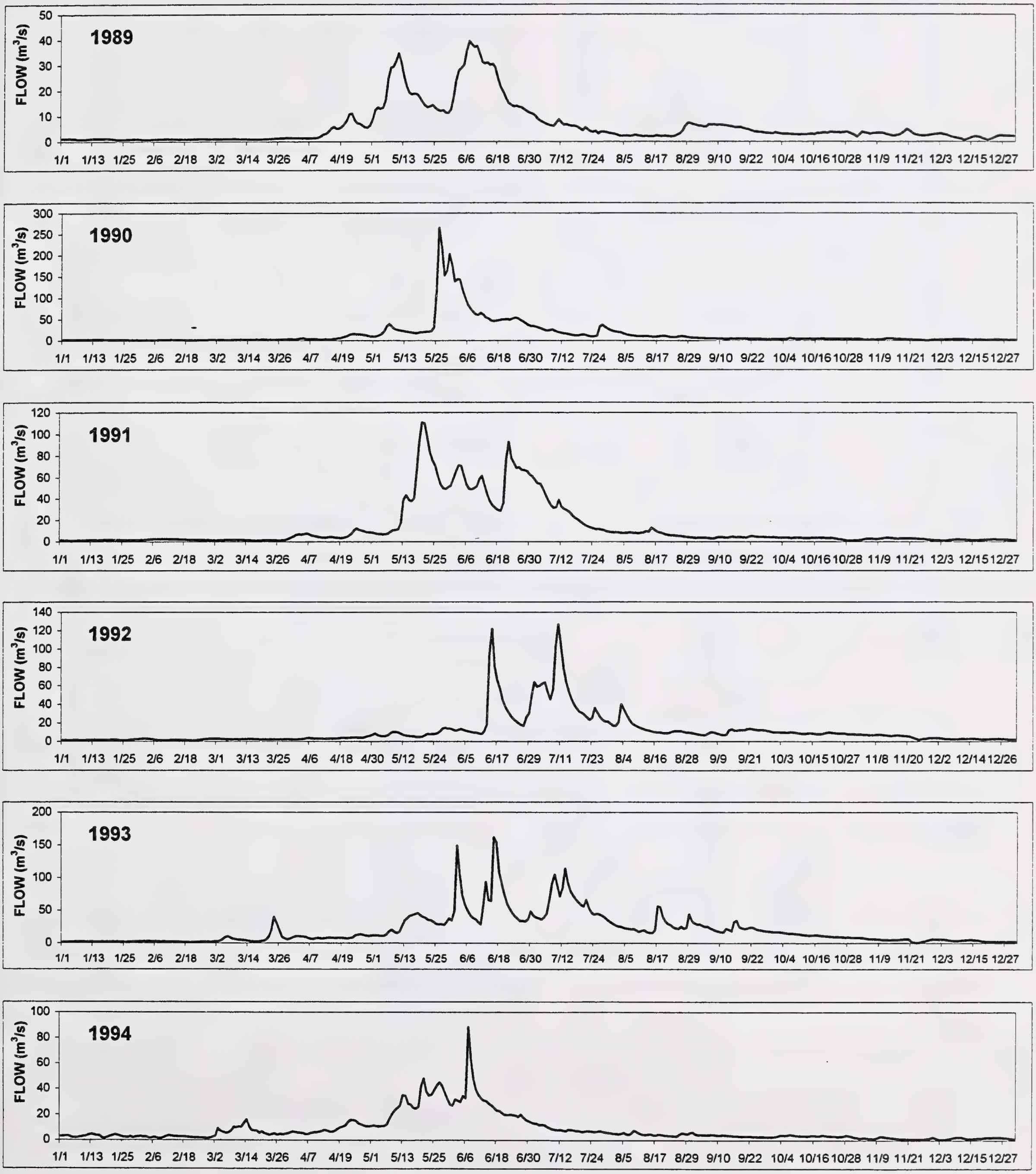


Figure 12 **Regression between total suspended solids (as nonfilterable residue) and flow in the Highwood River at the Little Bow Diversion Canal in High River**

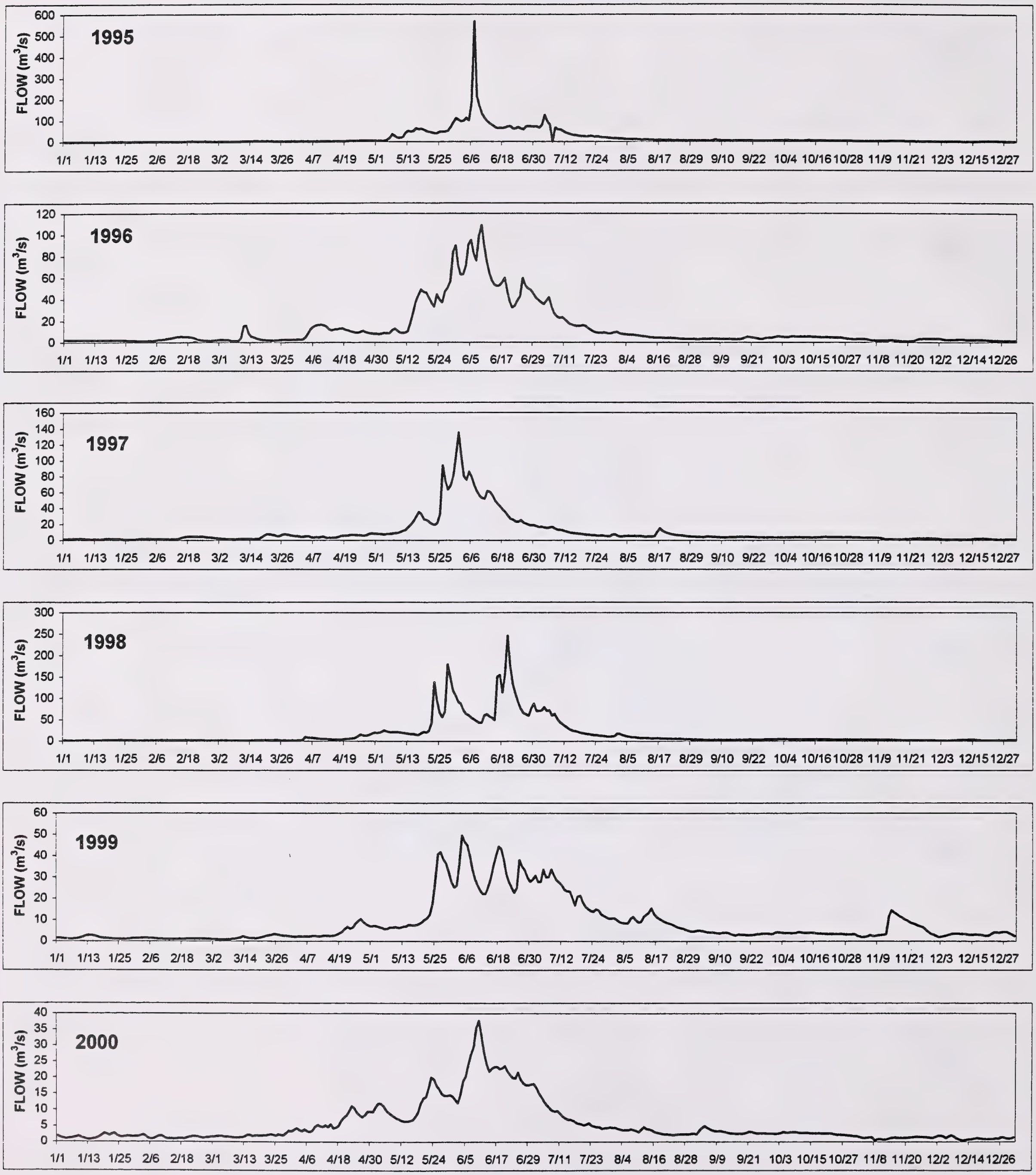
Appendix I

Highwood River near Aldersyde – 05BL2502. Water temperature, maximum air temperature, dissolved oxygen and flow, 1989-2000

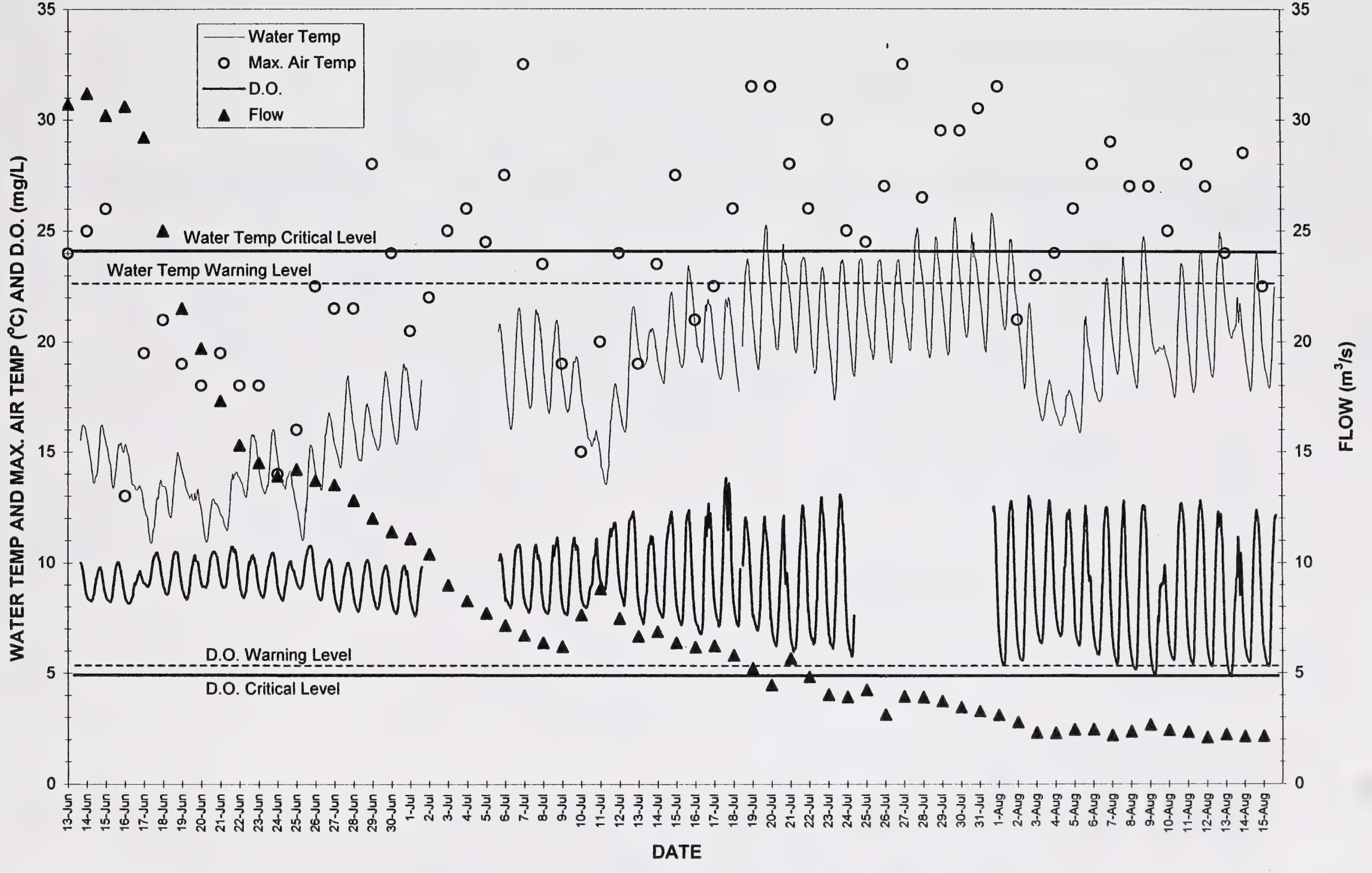
DAILY FLOWS IN THE HIGHWOOD RIVER BELOW LITTLE BOW CANAL (05BL004), 1989-1994



DAILY FLOWS IN THE HIGHWOOD RIVER BELOW LITTLE BOW CANAL (05BL004), 1995-2000



HIGHWOOD RIVER NEAR ALDERSYDE - 05BL2502
WATER TEMPERATURE, MAXIMUM AIR TEMPERATURE, DISSOLVED OXYGEN AND FLOW, 1989



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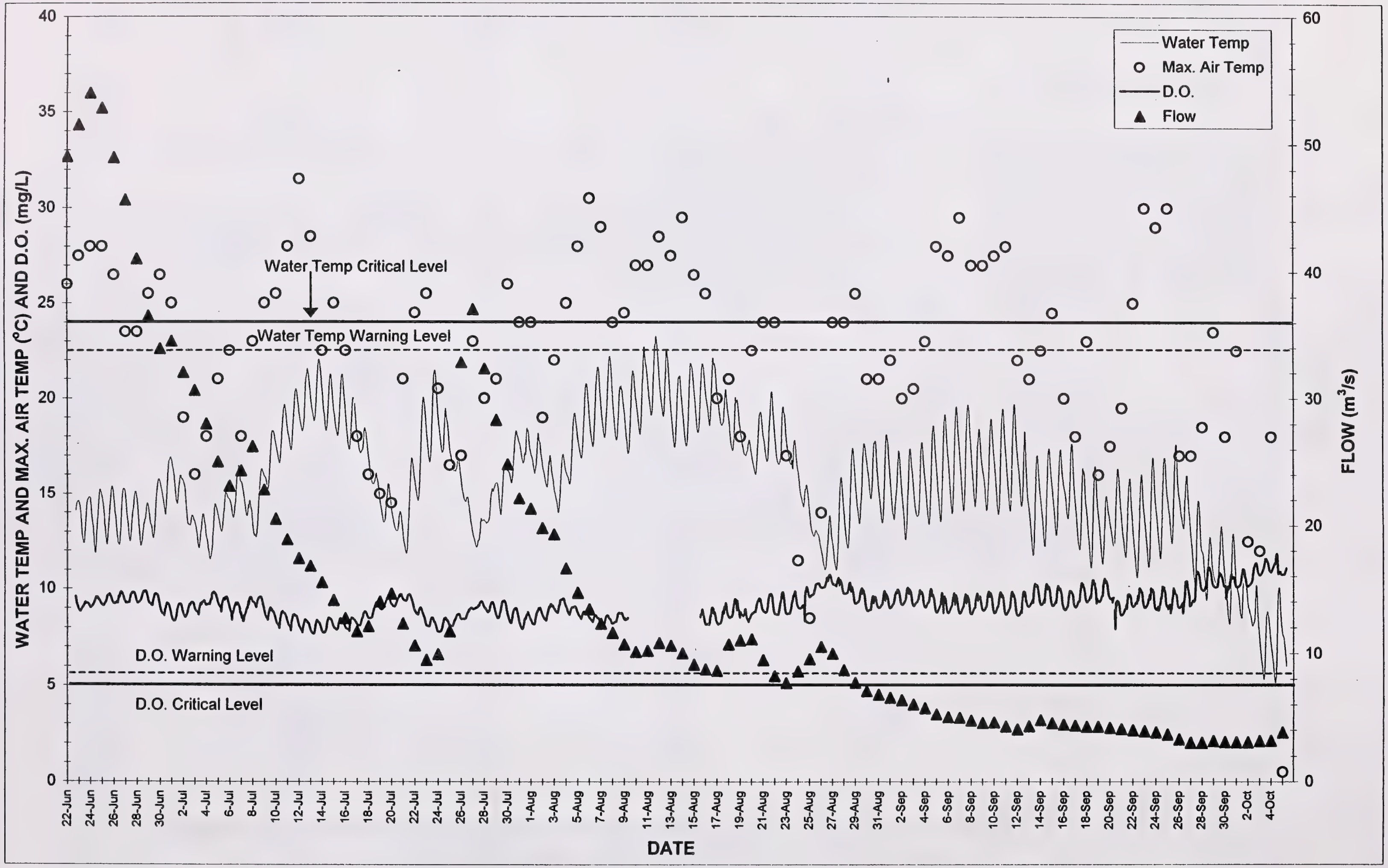
WATER TEMPERATURE, MAXIMUM AIR TEMPERATURE, DISSOLVED OXYGEN AND FLOW, 1990



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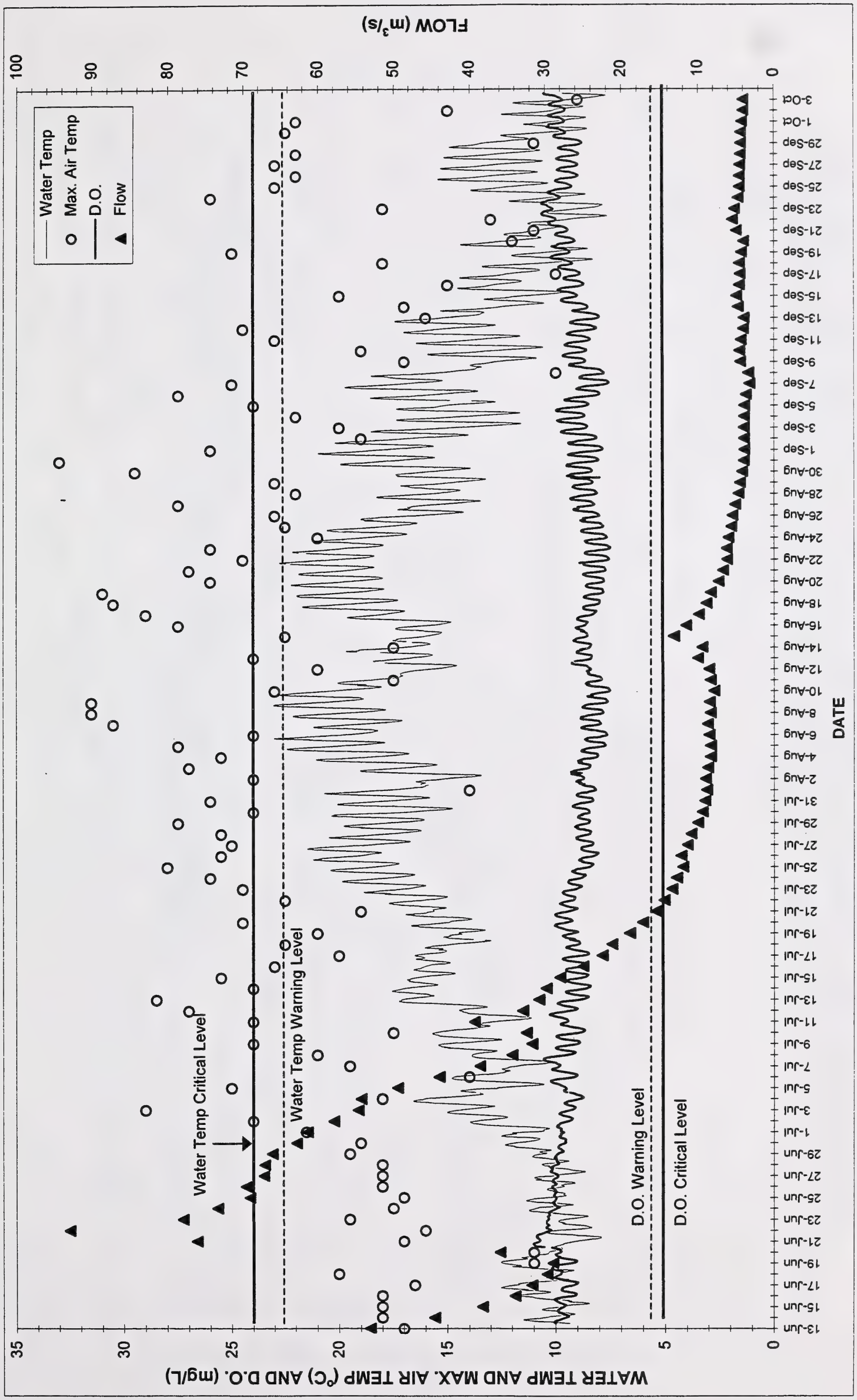

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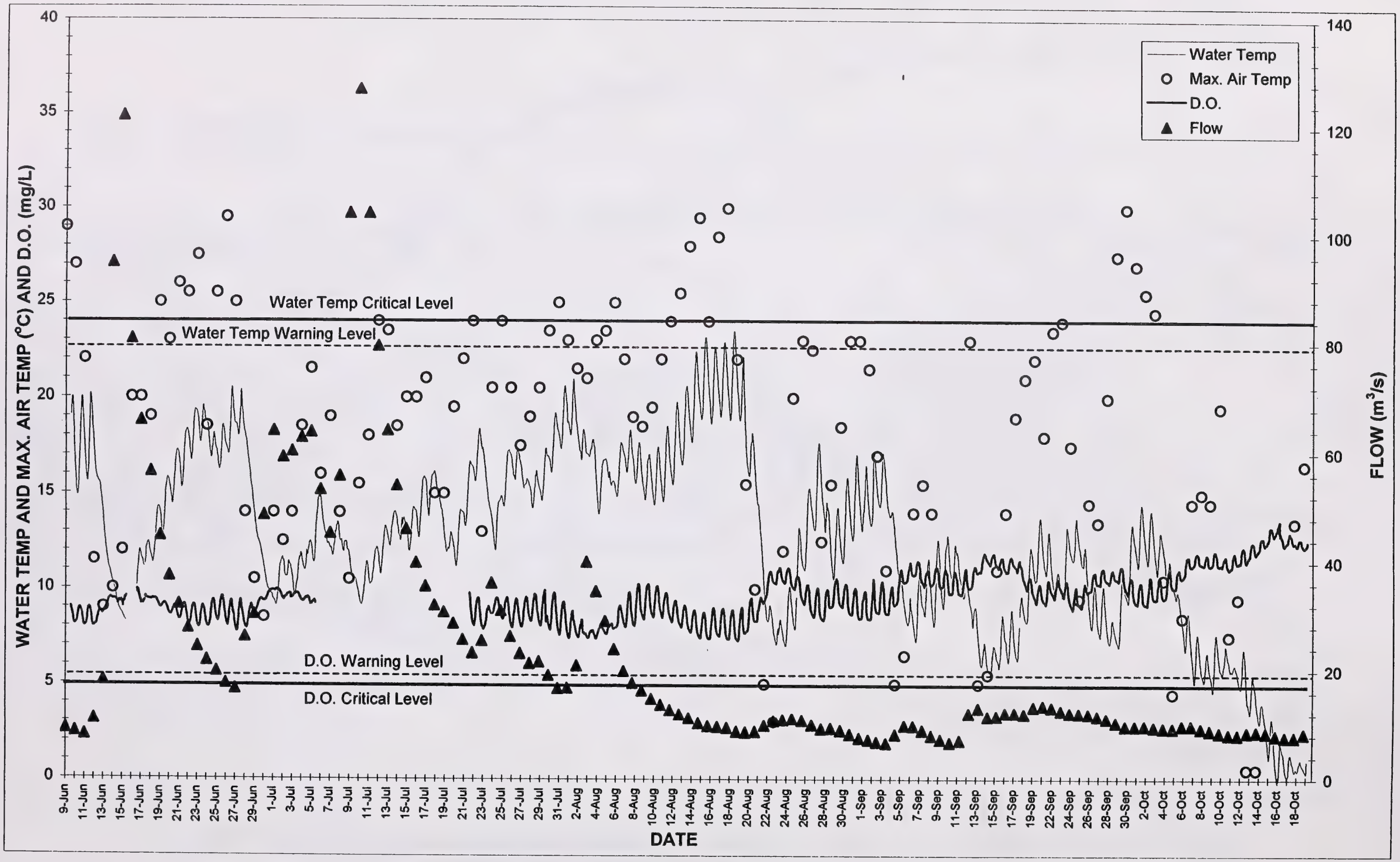

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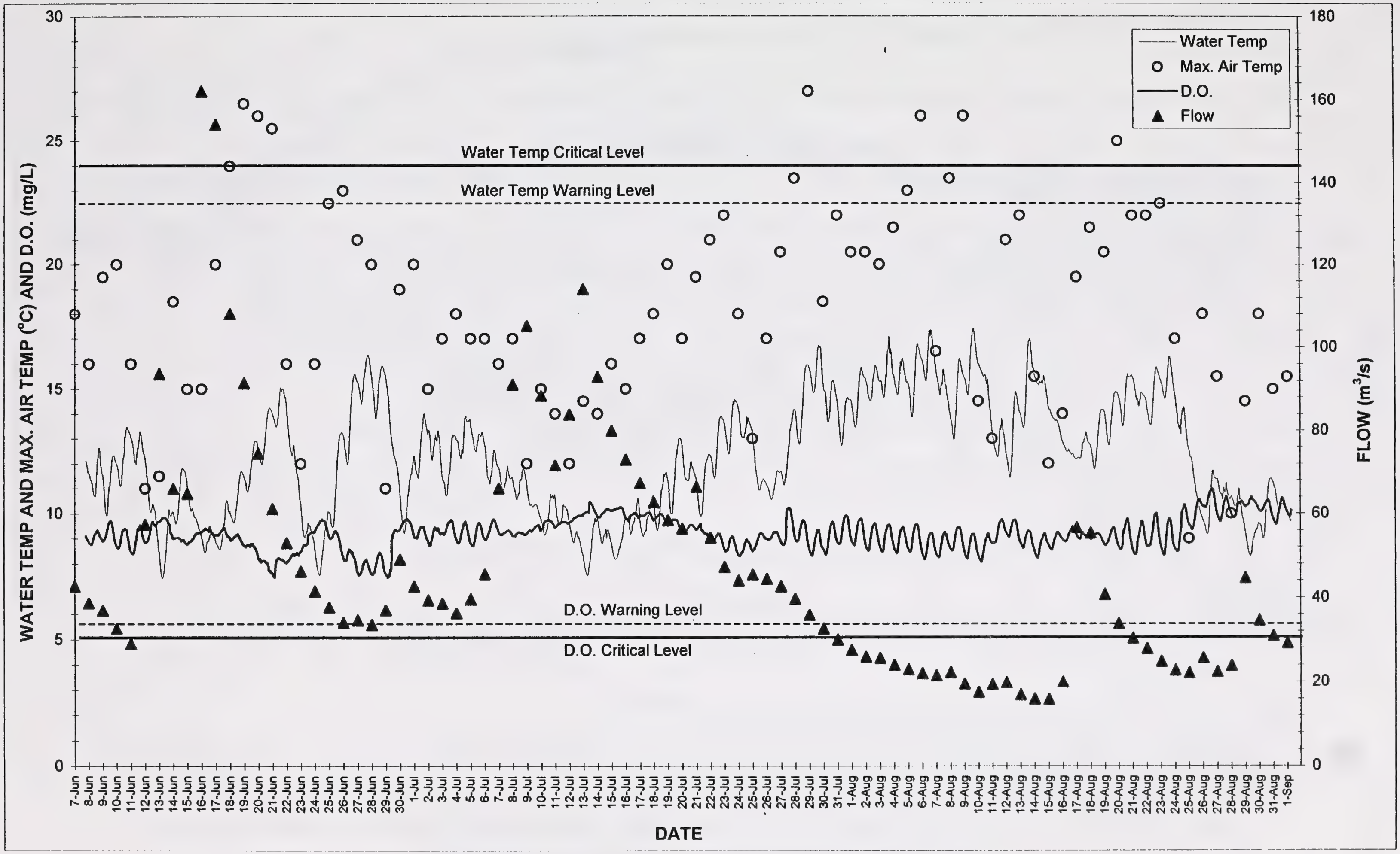

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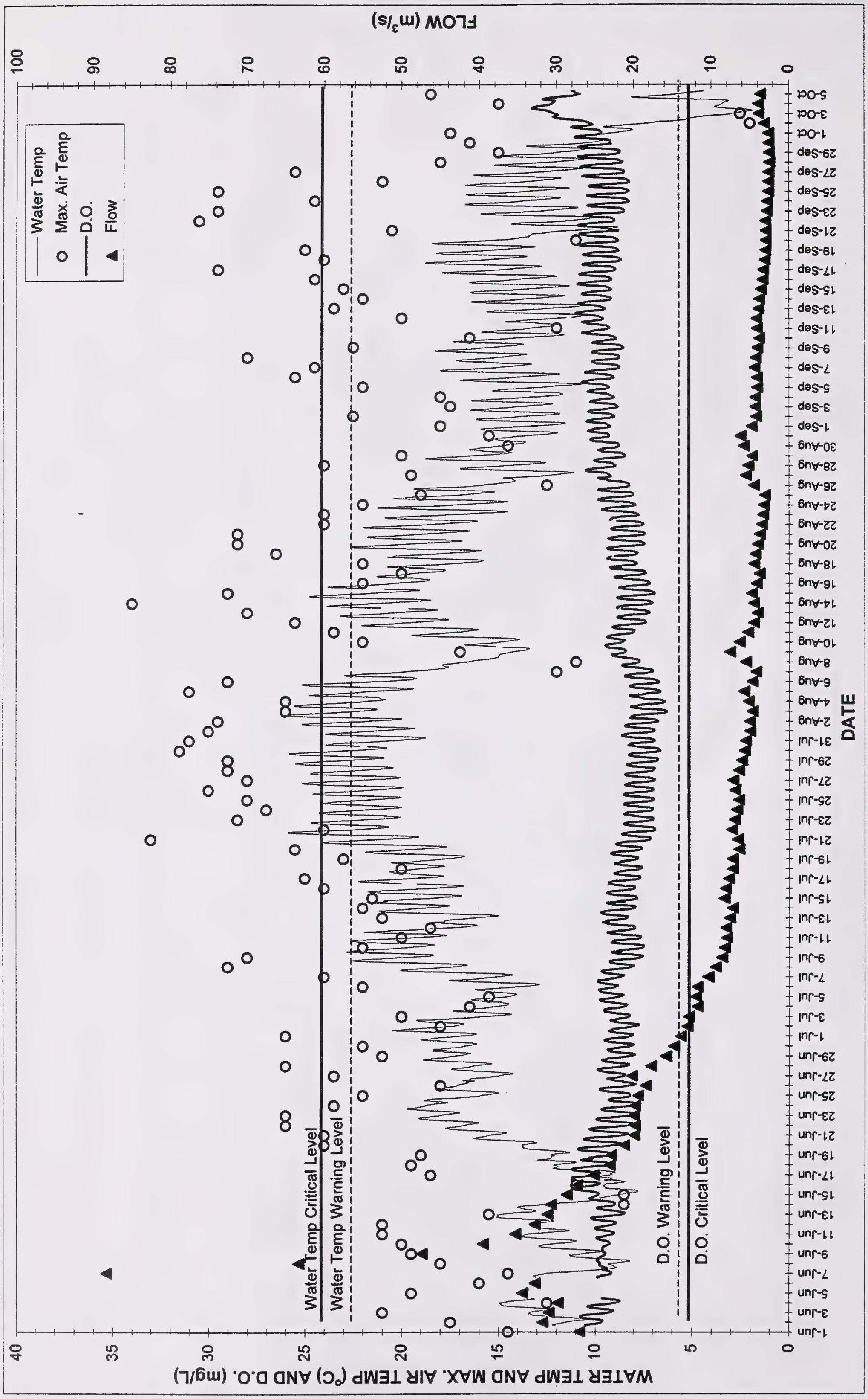

HIGHWOOD RIVER NEAR ALDERSYDE - 05BL2502

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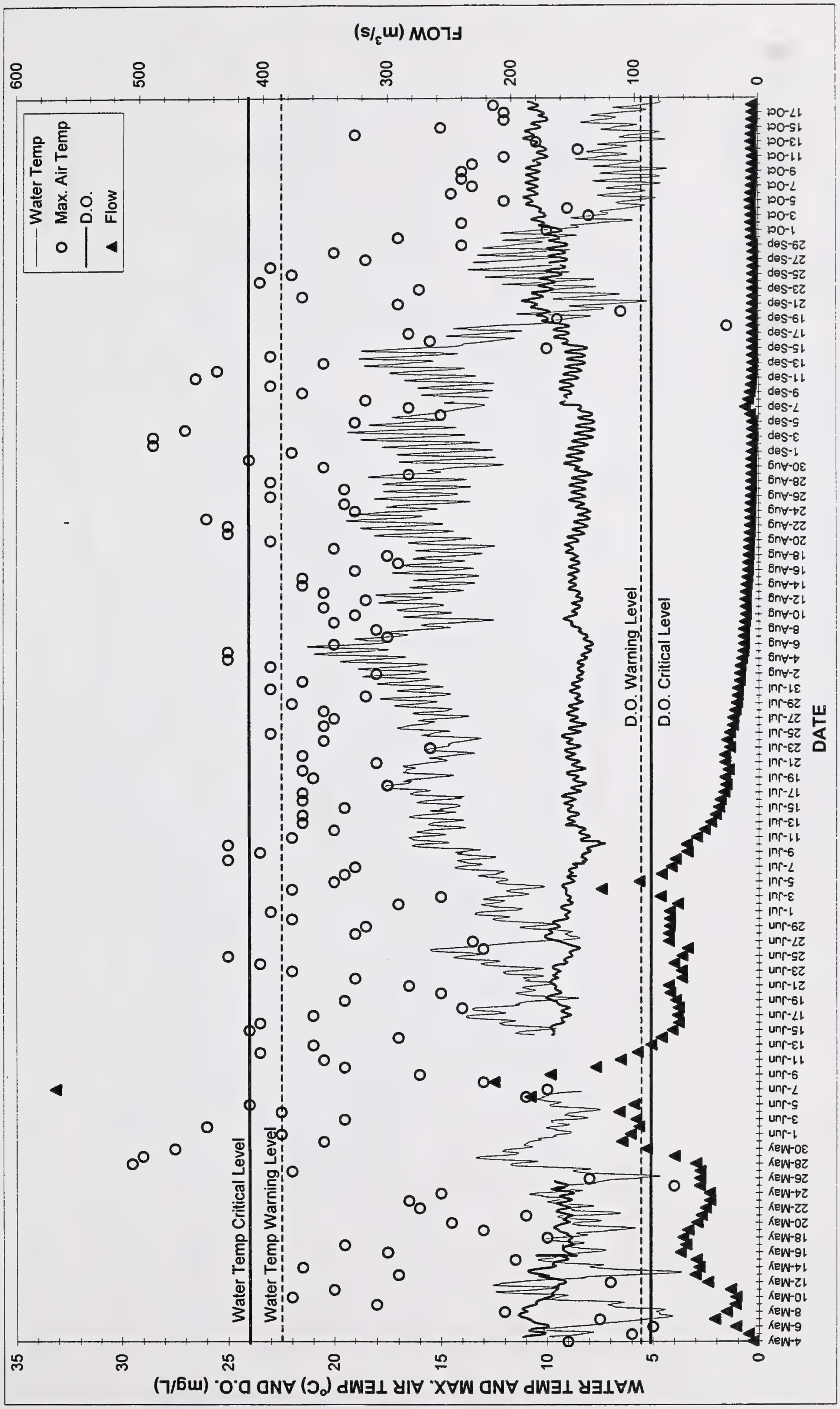

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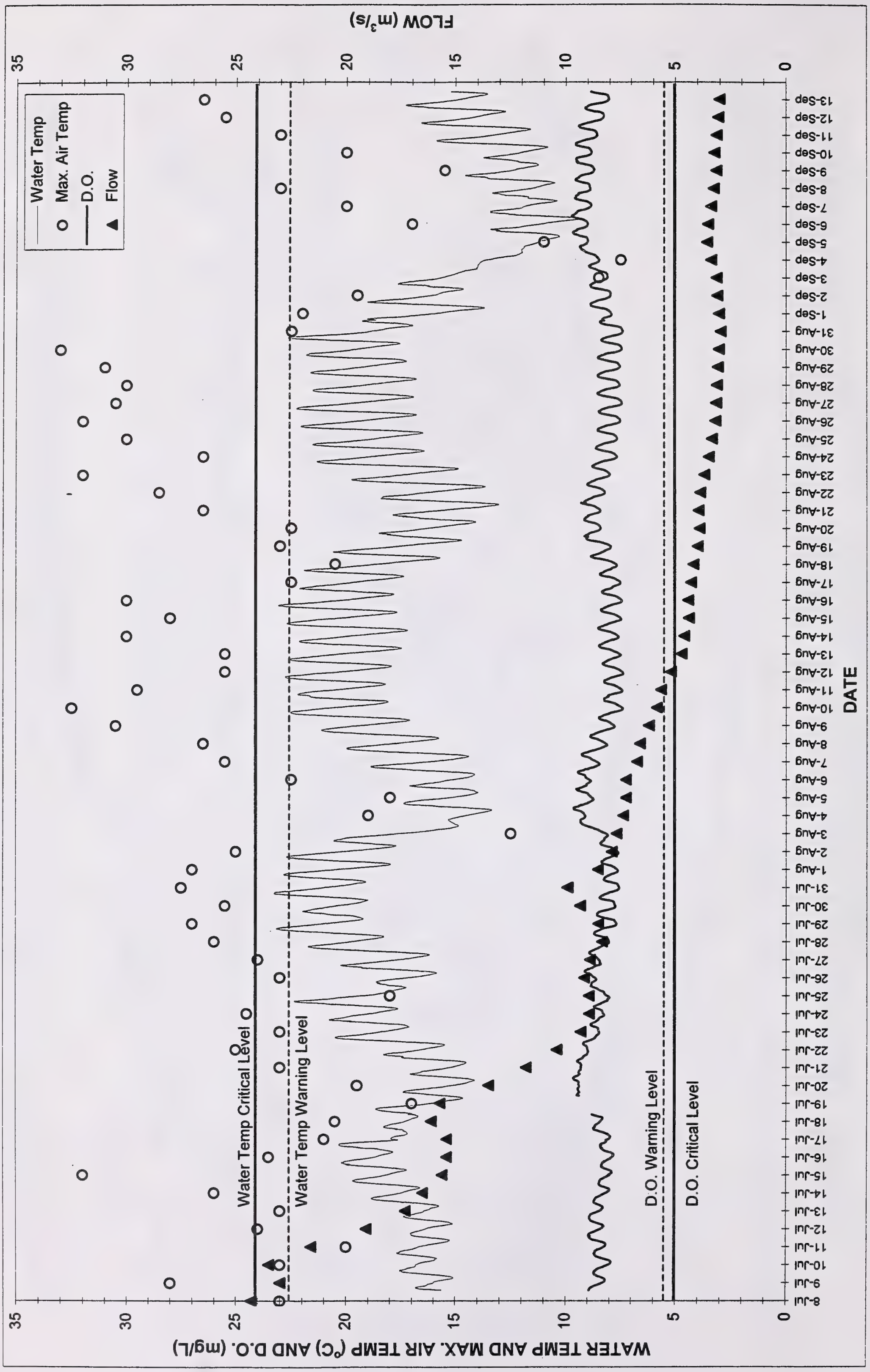

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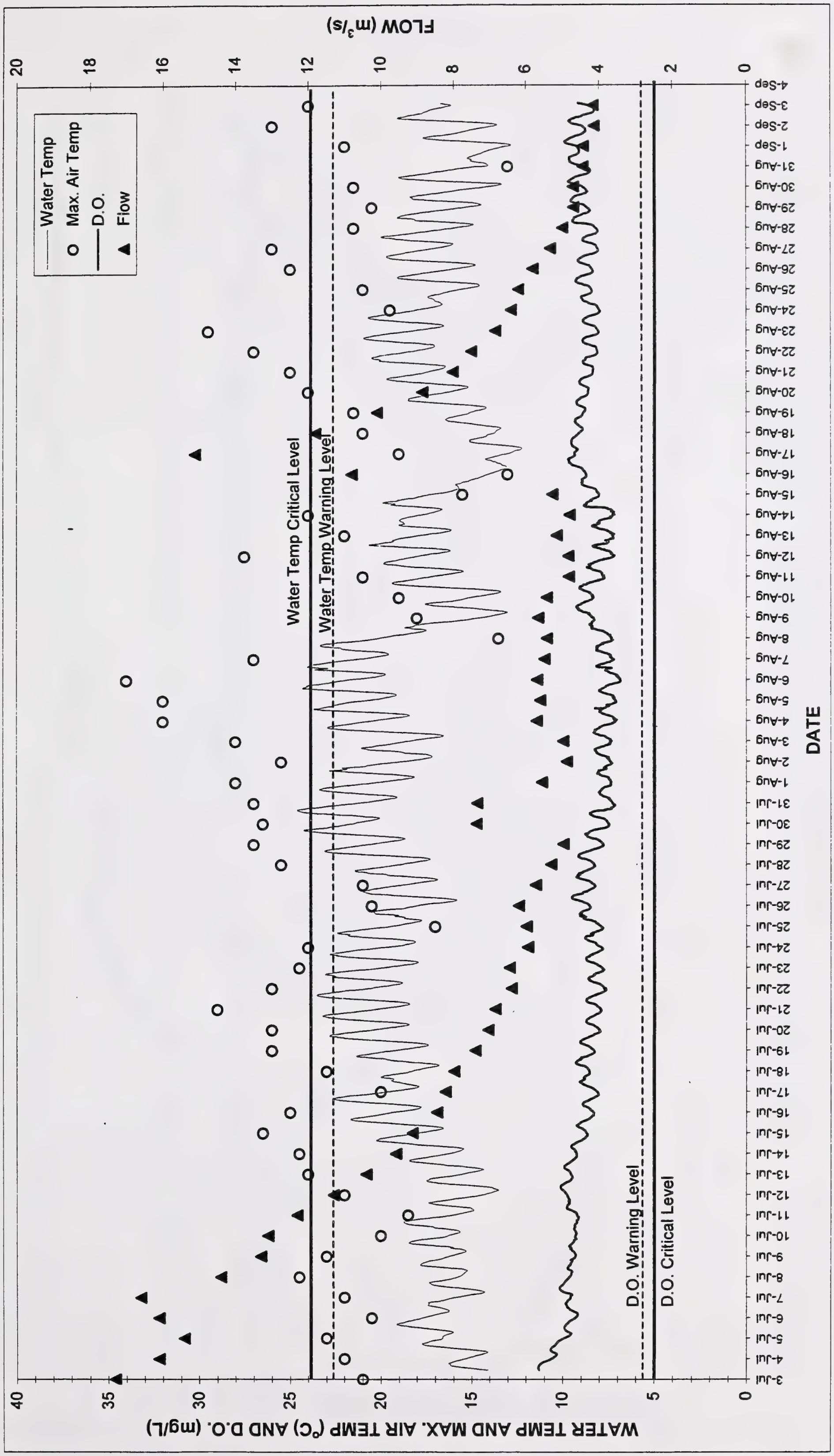

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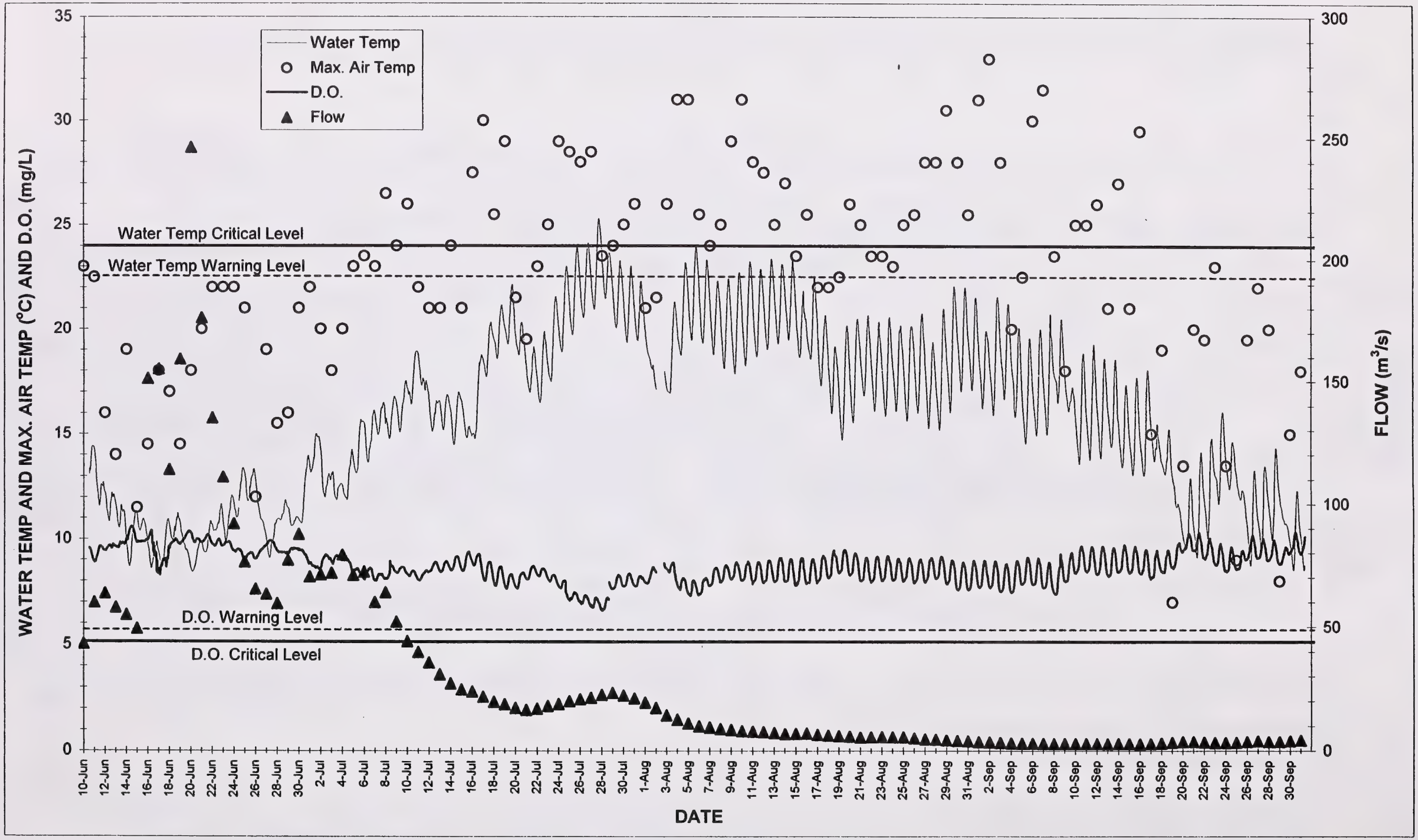

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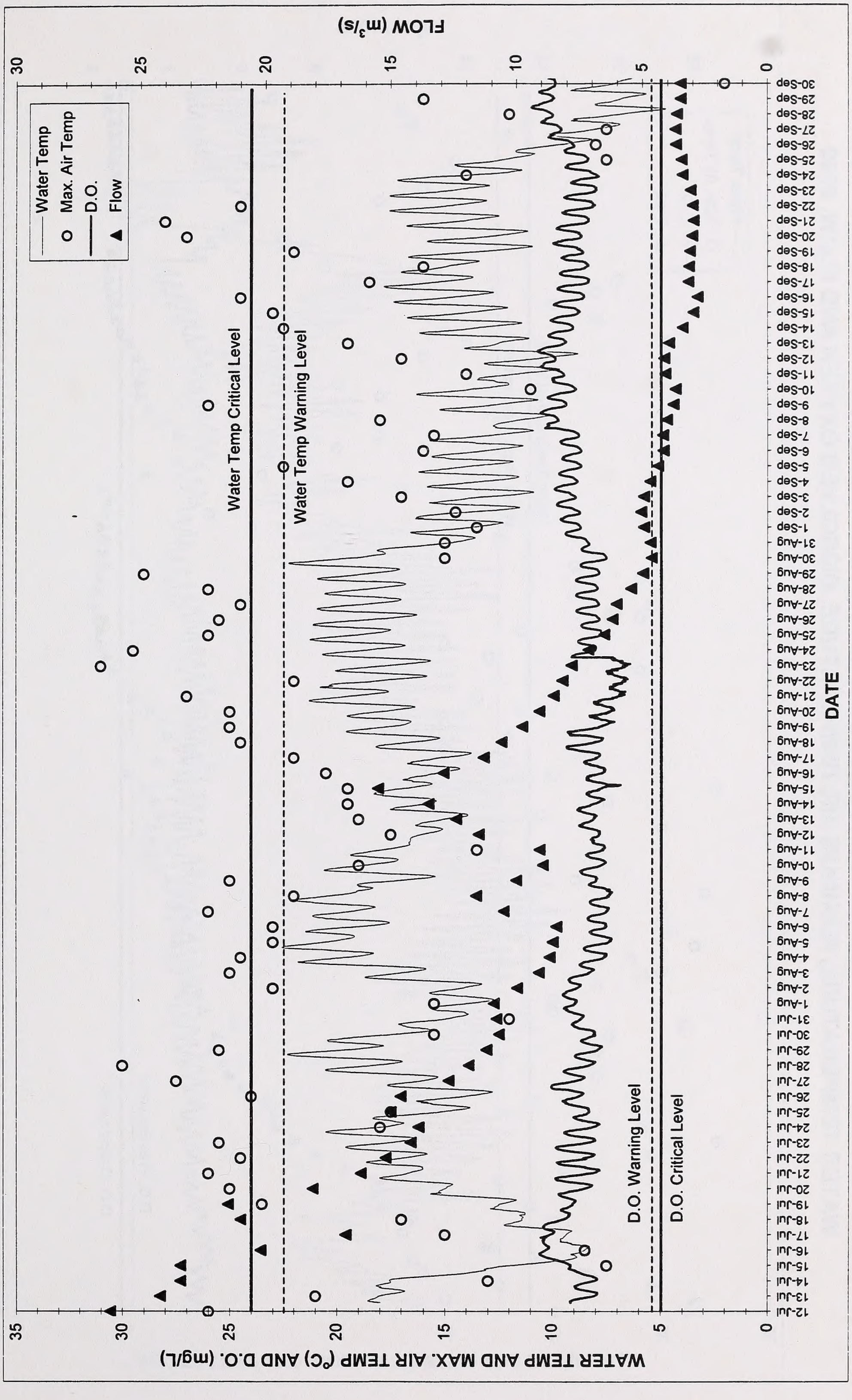

HIGHWOOD RIVER NEAR ALDERSYDE - 05BL2502

WATER TEMPERATURE, MAXIMUM AIR TEMPERATURE, DISSOLVED OXYGEN AND FLOW, 2000